NHDOT SPR2 PROGRAM
RESEARCH PROGRESS REPORT

Project # 26962O	**Report Period:** Year: 2018 ☒Q1 (Jan-Mar) ☐Q2 (Apr-Jun) ☐Q3 (Jul-Sep) ☐Q4 (Oct-Dec)	
Project Title: Incorporating Impact of Aging on Cracking Performance of Mixtures during Design		
Project Investigator: Jo Sias Daniel (Co-PI: Eshan Dave) **Phone:** 603-862-3277 **E-mail:** jo.daniel@unh.edu		
Research Start Date: December 1, 2016	**Research End Date:** September 30, 2018	**Project schedule status:** ☒ On schedule ☐ Ahead of schedule ☐ Behind schedule

Progress this Quarter (include meetings, installations, equipment purchases, significant progress, etc.):

The work conducted this quarter has focused on the aging, fabrication, specimen preparation, testing, and analysis of seven new mixtures received in 2017. The complex modulus, S-VECD fatigue, disc-shaped compact tension (DCT) and semicircular bending (SCB) fracture testing for all but the T3 mixture have been completed at the different aging levels. Table 1 shows the status summary for the project mixture testing. The results of linear viscoelastic characterization, fracture properties (DCT, SCB testing) and S-VECD fatigue properties of the tested mixtures completed this quarter are presented in the Appendix.

Table 1- Status Summary for Project Mixtures

Mixture ID	Binder PG Grade	NMAS (mm)	%TRB	Status						
				Received	Aging	Testing/Analysis				
						STOA	95°C@5d	85°C compacted	95°C@12d	135°C@ 24hr.
WM-S-1	PG 58-28	12.5	1.5	Done	Done	Done	Done	Done	Done	Done
WM-S-2	PG 58-28	12.5	1.0	Done	Done	Done	Done	Done	Done	Done
WM-S-3	PG 52-34	12.5	1.0	Done	Done	Done	Done	Done	Done	Done
WM-S-4	PG 52-34	12.5	1.5	Done	Done	Done	Done	Done	Done	Done
S-1	PG 58-28	9.5	1.0	Done	Done	Done	Done	NA	Done	Done
T4	PG 64-28	9.5	1.0	Done	Done	Done	Done	NA	Done	Done
SHS-1	PG 76-28	9.5	1.0	Done	Done	Done	Done	NA	Done	Done
SHM-1	PG 70-34	12.5	0	Done	Done	Done	Done	NA	Done	Done
SV-1	PG 64-28	9.5	0	Done	Done	Done	Done	NA	Done	Done
T3	PG 58-34	12.5	1.0	Done	Done	In Progress	In Progress	NA	In Progress	In Progress
T5	PG 64-28	12.5	1.0	Done	Done	Done	Done	NA	Done	Done

Done In Progress Not Started

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Table 2 below shows the testing that will be conducted on the extracted and recovered binders. The BBR and EBBR tests will be done by NHDOT, and the DSR testing will be done by UNH. Hollow cylindrical shells from gyratory specimens and specimens post testing for the four Westmoreland mixtures (WM-S-1, WM-S-2, WM-S-3, WM-S-4) were delivered to NHDOT for extraction and recovery in January. The field cores from these Westmoreland mixtures will also be sent to NHDOT for extraction and recovery after testing is completed. Table 3 shows the status summary for the extracted binder testing. Also, six of the seven binder samples sampled from the 2017 paving projects were received by UNH. The 4mm DSR testing is underway on the PAV samples to compare with the NHDOT BBR results for these materials. Table 4 shows the summary status for the binders sampled during production.

Table 2- Summary Table for Binder Tests

Tests	Virgin Binder (Sampled during production)	STOA	LTOAs	Field Cores
25mm DSR				
8mm DSR				
4mm DSR				
BBR				
EBBR				

Included Not Included

Table 3- Status Summary for Extracted and Recovered Binders

Binder Type	Mixture ID	NMAS (mm)	%TRB	Status					
				Sent to NHDOT for Extraction /Recovery	Extracted Binder received by UNH	Testing/Analysis			
						STOA	95°C@5d	95°C@12d	135°C@ 24hr.
PG 58-28	WM-S-1	12.5	1.5						
PG 58-28	WM-S-2	12.5	1.0						
PG 52-34	WM-S-3	12.5	1.0						
PG 52-34	WM-S-4	12.5	1.5						
PG 58-28	S-1	9.5	1.0						
PG 64-28	T4	9.5	1.0						
PG 76-28	SHS-1	9.5	1.0						
PG 70-34	SHM-1	12.5	0						
PG 64-28	SV-1	9.5	0						
PG 58-34	T3	12.5	1.0						
PG 64-28	T5	12.5	1.0						

Done Not Started

Table 4- Summary Table for Production Virgin Binder Samples

Binder Type	Mixture ID	NMAS (mm)	%TRB	Status				
				Sampled Binder Received by UNH	Testing/Analysis			
					Original	RTFO	PAV	
							BBR/8mm DSR	4mm DSR
PG 58-28	WM-S-1	12.5	1.5					
PG 58-28	WM-S-2	12.5	1.0					
PG 52-34	WM-S-3	12.5	1.0					
PG 52-34	WM-S-4	12.5	1.5					
PG 58-28	S-1	9.5	1.0					
PG 64-28	T4	9.5	1.0					
PG 76-28	SHS-1	9.5	1.0					
PG 70-34	SHM-1	12.5	0					
PG 64-28	SV-1	9.5	0					
PG 58-34	T3	12.5	1.0					
PG 64-28	T5	12.5	1.0					

Done by NHDOT   Done by UNH   In Progress   Not Started

Anticipated research next 3 months:

In the coming quarter, the research group plans to finish the testing of the available mixtures and the field cores and begin the binder testing once the extracted and recovered binder is available. UNH will continue to provide NHDOT with selected aged mixtures for extraction and recovery of binder for subsequent testing.

Circumstances affecting project: Describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope, and budget, along with recommended solutions to those problems.

Tasks (from Work Plan)	**Planned % Complete**	**Actual % Complete**
Literature Review and Testing Plan	**100**	**100**
Laboratory Aging of Mixtures	**100**	**100**
Mixture Material Characterization Testing and Analysis	**70**	**95**
Characterization of Extracted and Recovered Binders and Analysis	**25**	**5**
Development of Screening Tool and Guidelines	**0**	**0**
Reporting	**0**	**0**

The characterization of extracted and recovered binders is behind schedule due to issues that NHDOT has been working through with the extraction and recovery of these materials.

Appendix:

Results and Discussion
Linear Viscoelastic Parameters

Complex modulus testing and analysis conducted this quarter are presented as the average of three replicates for three mixtures (T5, PG 64-28, 12.5mm, 16.9%RAP; SV, PG 64-28, 9.5mm, NO RAP; and S1, PG 58-28, 9.5mm, 16.9%RAP) in Figures 1 and 2. The trend is similar to the previous mixtures evaluated in this project: as the asphalt materials age, the stiffness (IE*I) increases while the relaxation capability of mixtures, as represented by phase angle (δ), decreases. Statistical analysis shows that there is a significant difference between the dynamic modulus and phase angle of mixtures in short term aged condition (STOA) and all other levels of aging. There is also a statistically significant difference between the 5d@95°C and the 12d@95°C aging conditions. The 24hr.@135°C and 12d@95°C conditions are statistically similar.

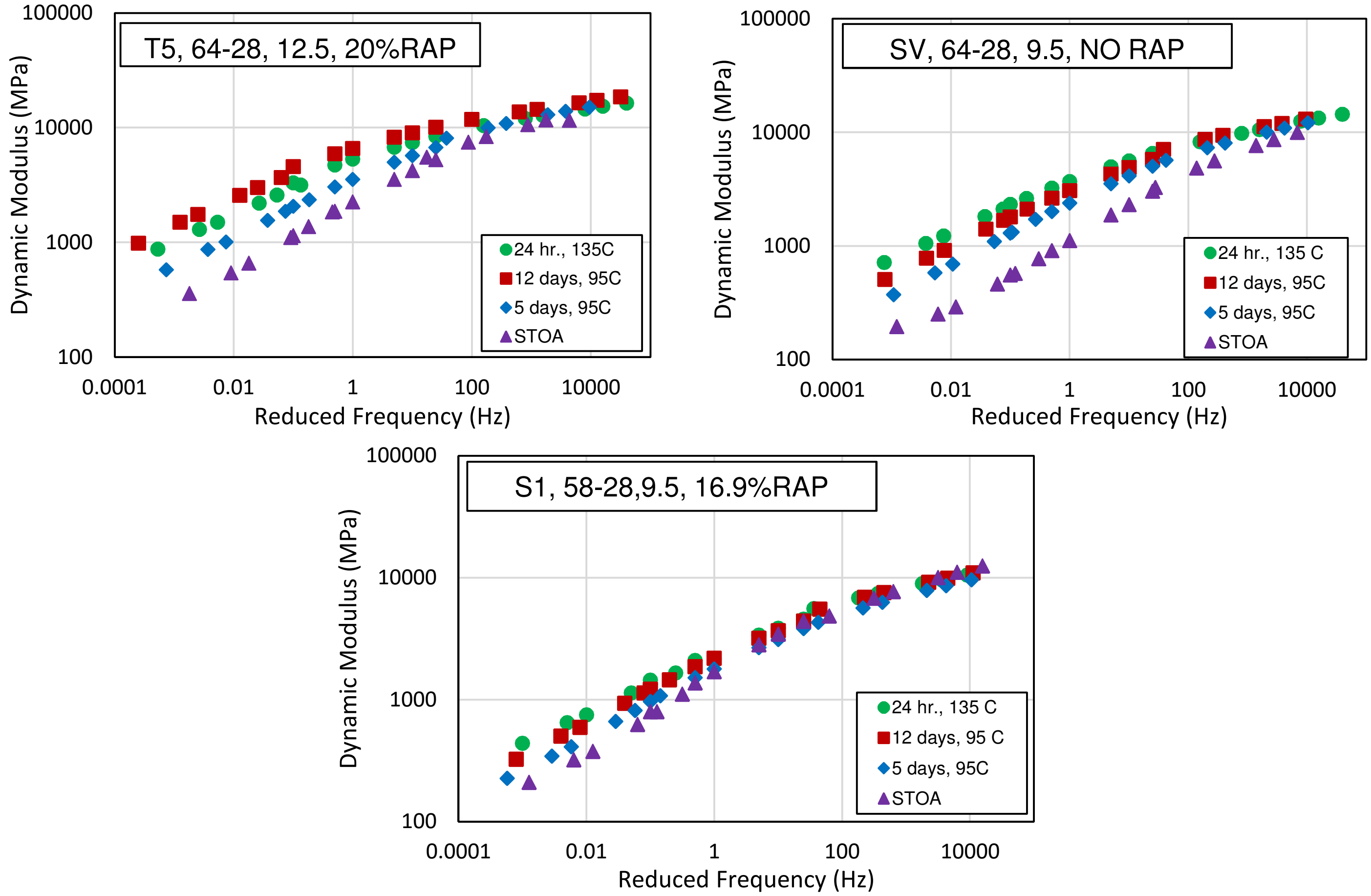


FIGURE 1 Dynamic Modulus Master Curves for T5 Mixture (PG 64-28, 12.5mm, 16.9%RAP), SV Mixture (PG 64-28, 9.5mm, NO RAP) and S1 Mixture (PG 58-28, 9.5mm, 16.9%RAP) at Different Aging Levels

To capture the combination of stiffness and relaxation capability of mixtures in a single plot, the Black space diagram is shown in Figure 2. The figure shows the Black space movement with the change of aging conditions. The inflection point moves towards the bottom left as more aging occurs. The observations in Black space diagram can be used to estimate thermal cracking susceptibility of asphalt mixtures. Generally, a mixture with higher stiffness at a constant phase angle is expected to incur greater thermal stress values. If the relaxation capability (phase angle) of this mixture is lower, the mixture relieves the thermal stress at a lower rate, resulting in higher thermal cracking potential. In Figure 2, at a constant value of stiffness (|E*|), phase angles for STOA condition are higher than those after long term aging conditions. This indicates that for the same level of thermal stress, the relaxation capability decreases with aging and the material becomes more likely to crack.

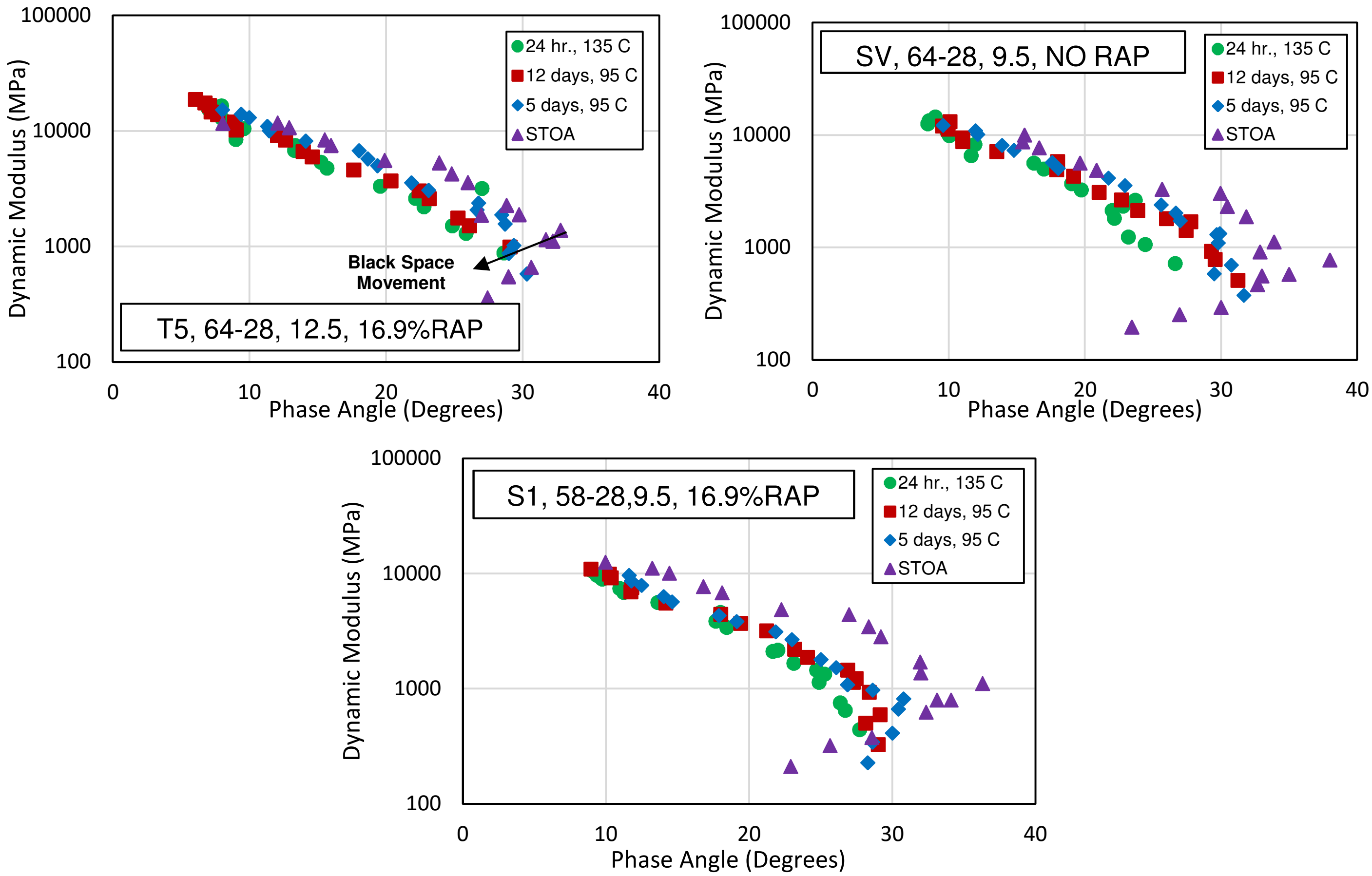


FIGURE 2 Black Space Diagrams for T5 Mixture (PG 64-28, 12.5mm, 16.9%RAP), SV Mixture (PG 64-28, 9.5mm, NO RAP) and S1 Mixture (PG 58-28, 9.5mm, 16.9%RAP) at Different Aging Levels

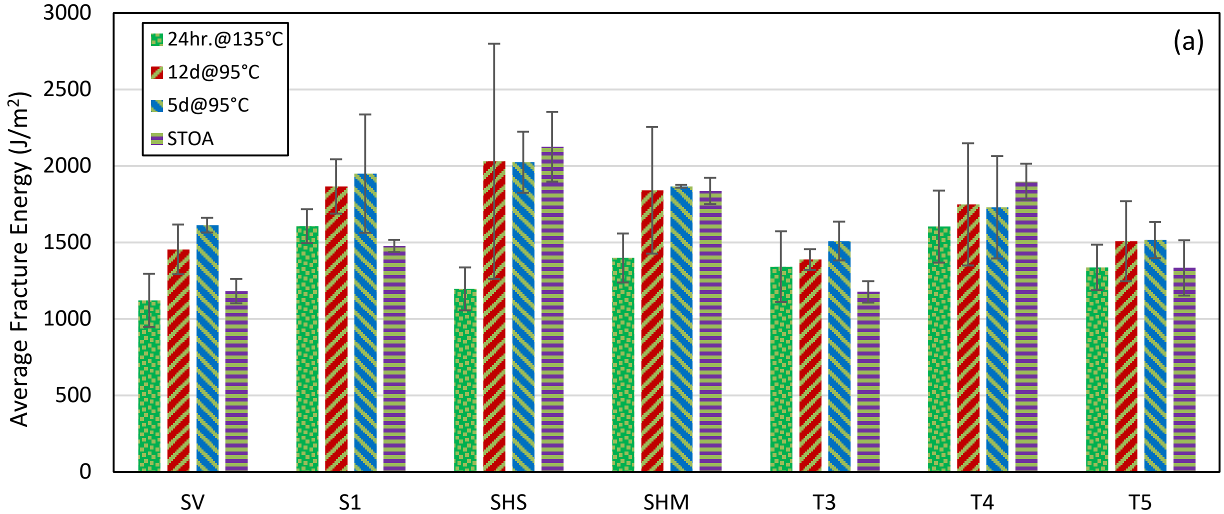
Fracture Parameters

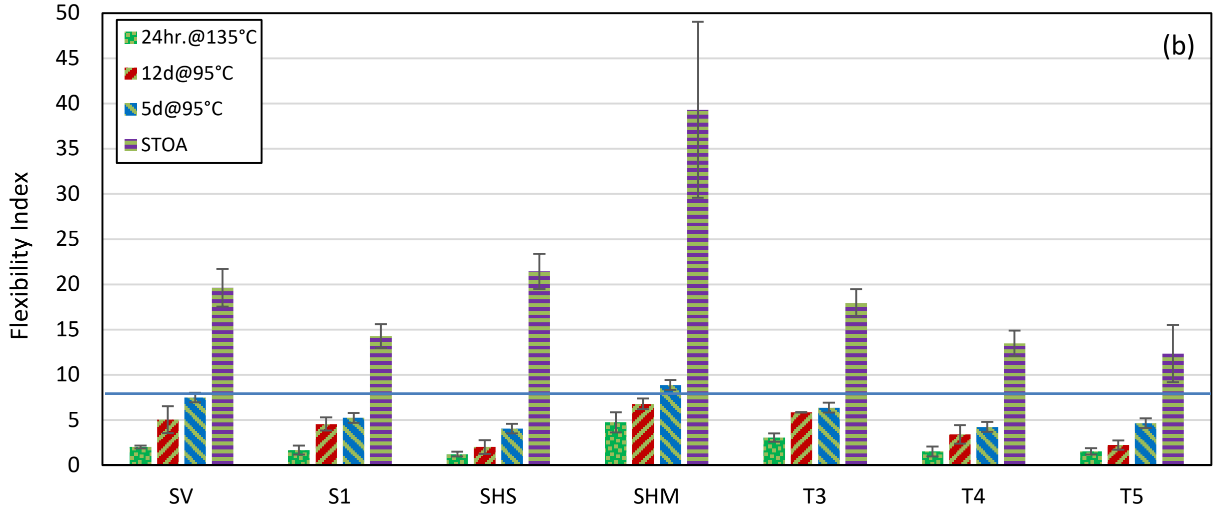
The results of SCB and DCT testing conducted for the 7 new mixtures are presented and discussed in this section.

SCB Testing

The SCB testing is conducted at 25°C for all mixtures. Figure 3a and 3b show the average fracture energy (G_f) and the flexibility index (FI) parameter which is the average of 3 to 4 replicates for each mixture with the standard deviation error bars. There is no clear trend for the fracture energy (G_f) of the mixtures from different aging levels. The flexibility index (FI) decreases when aging level changes from STOA to 5d@95°C, 12d@95°C and 24hr.@135°C. There is a statistically significant difference in flexibility index (FI) between the STOA and the three long term aging levels. This indicates that the mixtures lose cracking resistance very quickly with aging. Another interesting observation is that even though the SHM (polymer modified mixture with virgin binder) has the best performance in term of flexibility index (FI) at the STOA condition, the difference as compared to other mixtures reduces with aging. This indicates aging has a larger influence on this mixture. The light blue line in Figure 3b is the proposed FI threshold (FI=8); mixtures with FI values below the threshold are expected to be susceptable to cracking. The results show that most of the mixtures after 5d@95°C aging will be likely to have cracking issues.

Figure 3c shows the flexibility index (FI) aging ratio (LTOA divided by STOA). Generally, the flexibility index aging ratio decreases with aging. Intermediate aging causes the FI to drop to 20-40% of the STOA condition while long term aging drops the FI to 5-30% of the STOA condition. The 24hr.@135°C condition causes a larger drop than the 12d@95°C. The SHS and SHM mixtures, which have the polymer modified binders with the largest useful temperature interval (UTI=104), show the most impact from aging on FI values.





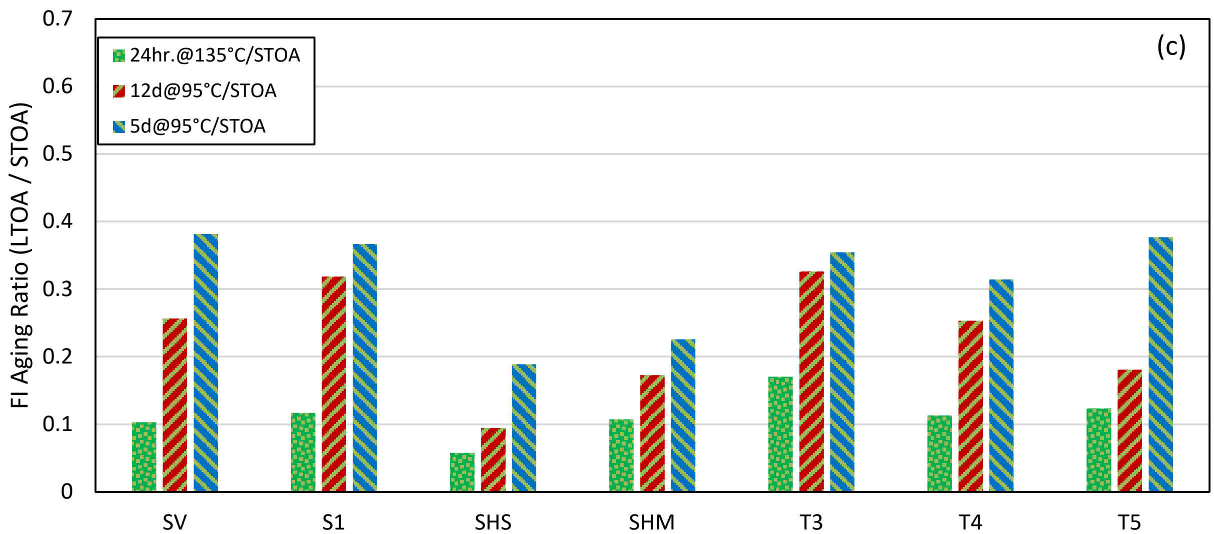
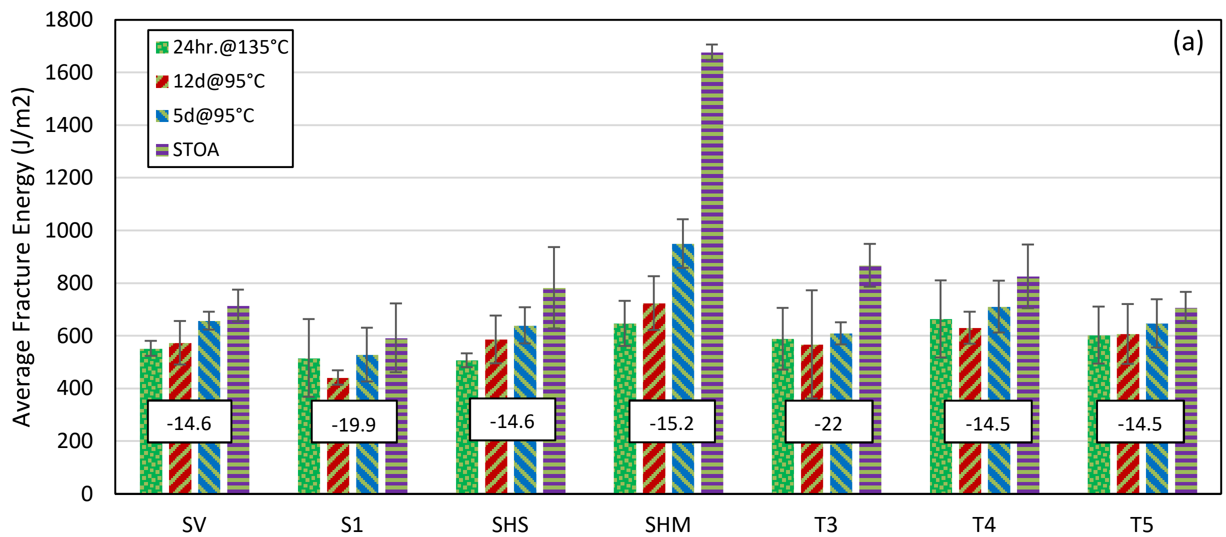


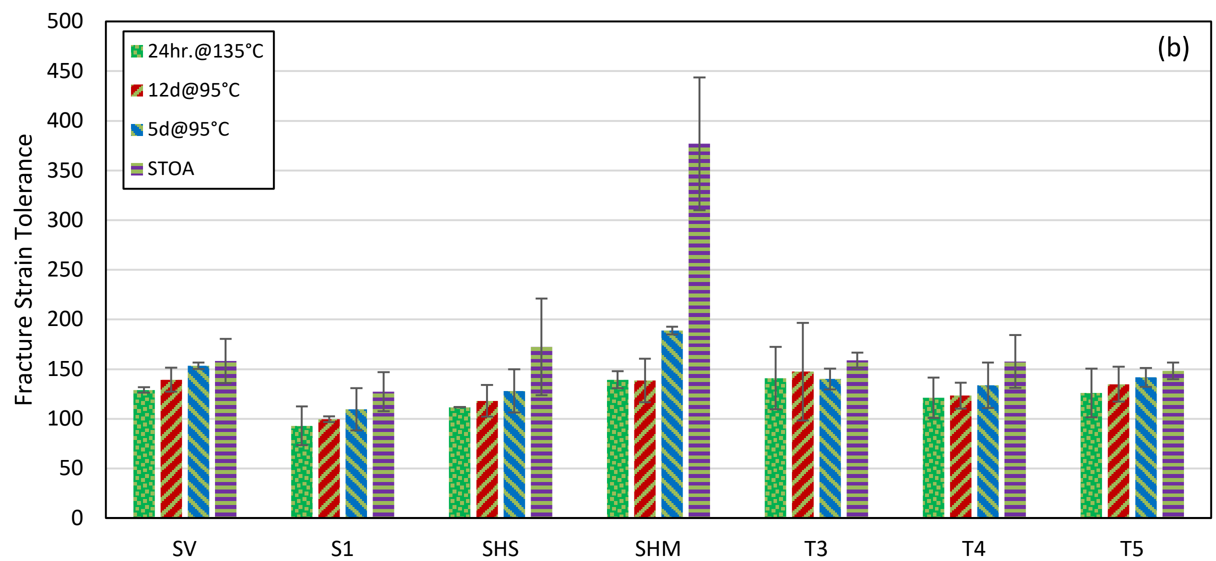
FIGURE 3 (a) Fracture Energy and (b) Flexibility Index Values from SCB tests (C) Flexibility Index Aging Ratio from SCB Tests

DCT Testing

The DCT testing temperature is based on the in-service location, as shown in Figure 4a. Figures 4a and 4b show the average fracture energy (G_f) and fracture strain tolerance (FST) for the 7 new mixtures at different aging levels. Generally, fracture energy (G_f) decreases when aging level increases, with a statistically significant difference between the STOA and the two long term aging levels. The trend between the two longer term aging levels varies with mixture. The fracture strain tolerance (FST) trend is similar, decreasing with longer aging levels. This general trend of the two parameters are similar to the flexibility index (FI) result from the SCB test.

Figure 4c shows fracture strain tolerance (FST) aging ratio (LTOA divided by STOA). Generally, the FST aging ratio decreases with longer aging times with the 24hr.@135°C condition typically being the most severe. The SHS and SHM mixtures have the largest decrease in FST with aging, similar to what was observed with the SCB testing.





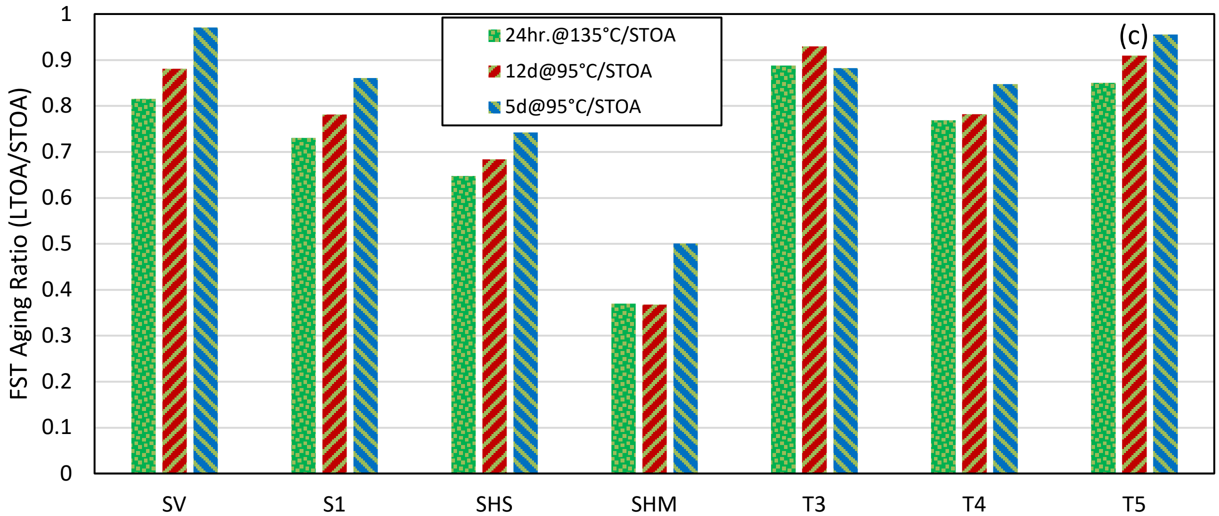
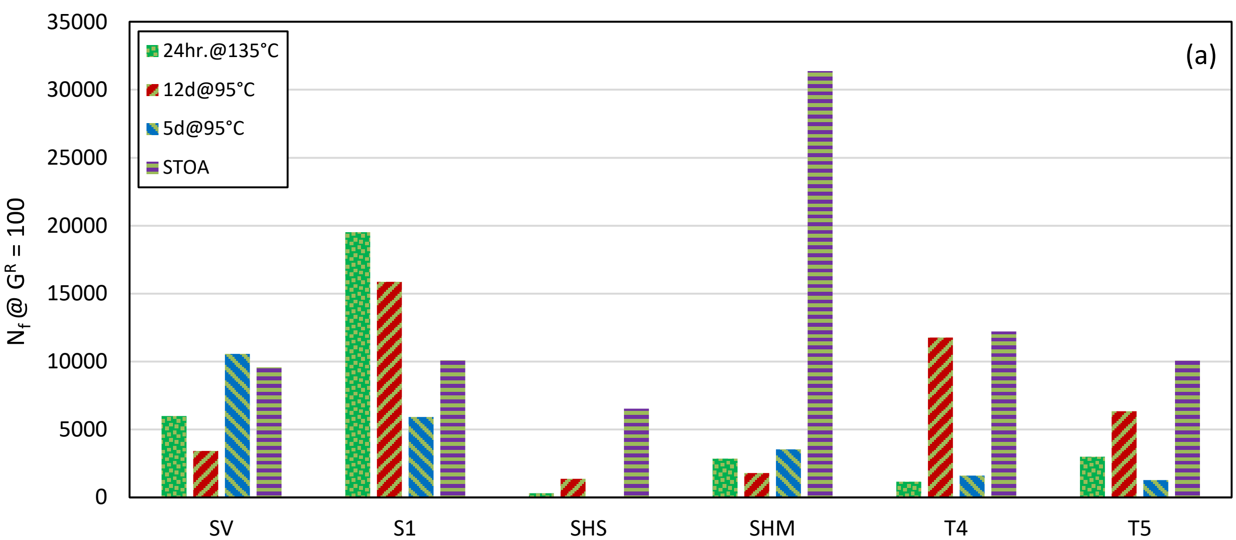


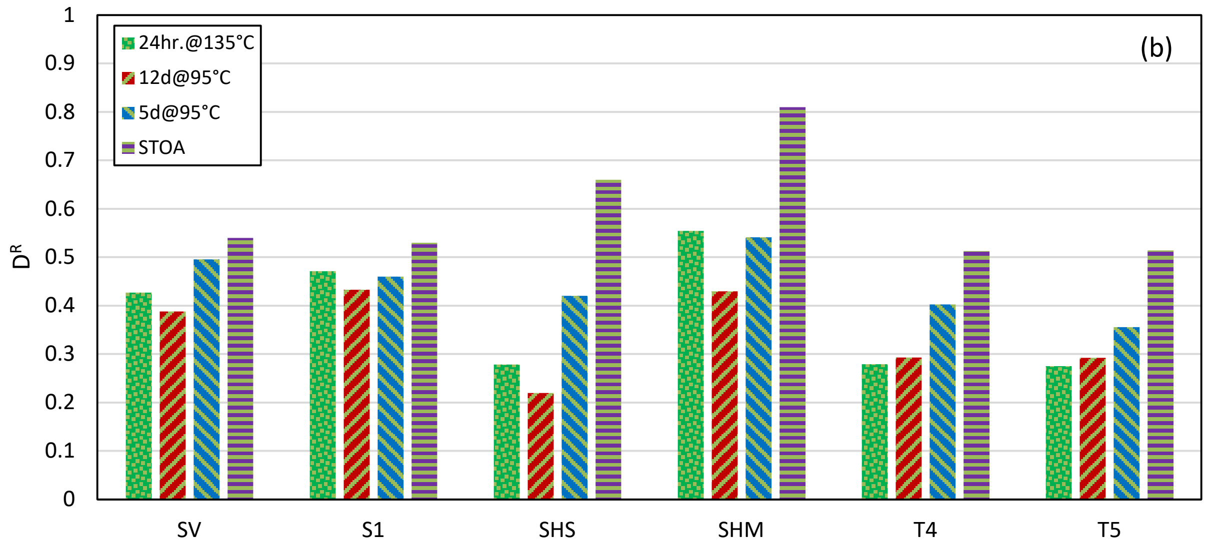
FIGURE 4 (a) Fracture Energy and (b) Fracture Strain Tolerance Values (C) Fracture Strain Tolerance Aging Ratio from DCT Tests

S-VECD Fatigue Testing

Figures 5a and 5b show the N_f @ G^R = 100 and D^R (average reduction in pseudo stiffness up to failure) for 6 of the new mixtures at different aging levels. There is no clear trend in the N_f @ G^R = 100 criteria for the different mixtures with aging level. The D^R criteria shows a more consistent trend with decreasing value with aging from STOA to 5d@95°C and 12d@95°C, which is similar to the SCB and DCT results. The two long term levels are different, with the trend changing for each mixture. Also, there is a statistically significant difference in D^R between the STOA and two long term aging levels, and the differences between the intermediate (5d@95°C) and long term aging levels vary by mix.

Figure 5c shows the D^R aging ratio (LTOA divided by STOA). Generally, the D^R ratio decreases increasing aging. The difference in the D^R aging ratio between 12d@95°C and 24hr.@135°C conditions varies by mix. Similar to the SCB and DCT results, the SHS and SHM mixtures show the largest drop with aging as compared to the other mixtures.





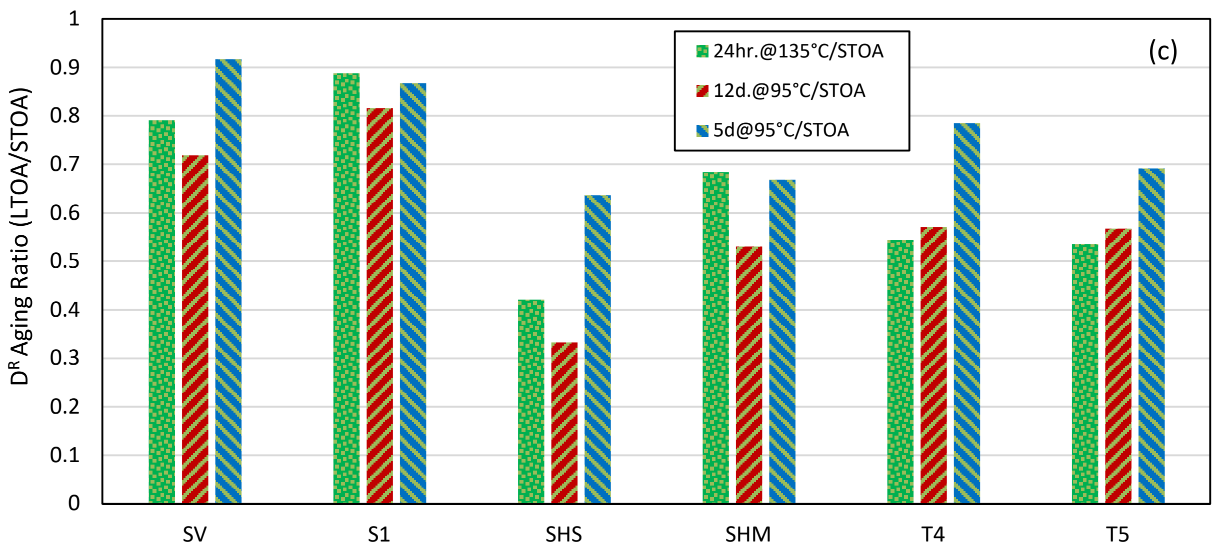


FIGURE 5 (a) $N_f@G^R$=100 and (b) D^R Values (C) D^R Aging Ratio from S-VECD Fatigue tests